

No. 6. — *The Intrusive and Extrusive Triassic Trap Sheets of the Connecticut Valley.* By WILLIAM MORRIS DAVIS and CHARLES LIVY WHITTLE.

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1. — Introductory.

THE outcrops of conglomerate, sandstone, and shale in the Triassic formation of the lower Connecticut Valley are generally inconspicuous, and alone would hardly afford means of deciphering the structure of the region; but they are accompanied by ridges of strong relief, marking the resistant edges of trap sheets whose close conformity to the adjacent sedimentary beds has long been recognized. It was noticed by the elder Hitchcock that some of these sheets were extrusive. Manifestly these are of great stratigraphic value, for after taking their places in the stratified series, they constitute truly conformable members of the mass, and may be used as guides to the deformations that the whole has suffered.<sup>1</sup> Attention was called to their value in this respect by the senior author of this essay in 1883,<sup>2</sup> and since then something of the structure of the region has been worked out<sup>3</sup> for the United States Geological Survey by means of the dislocations of the sheets that are regarded as extrusive. The field about Meriden has also been found an

<sup>1</sup> Chamberlin and Irving. Bull. 23, U. S. G. S., 1885, pp. 100, 101.

<sup>2</sup> Amer. Journ. Science, XXIV., 1882, p. 347. Bull. Museum Comp. Zoöl., Geol. Ser., I., 1883, p. 249.

<sup>3</sup> Amer. Journ. Science, XXXII., 1886, p. 342. Amer. Assoc. Proc., XXXV., 1886, pp. 224-227. Seventh Ann. Rep. U. S. G. S., 1888. Bull. Museum Comp. Zoöl., Geol. Ser., II., 1889, pp. 61-87. Amer. Journ. Science, XXXVII., 1889, pp. 423-434. Meriden Scient. Assoc. Proc., 1889.

excellent training ground for the Harvard Summer School of Geology. There is, however, still difference of opinion as to which of the trap sheets are of extrusive origin, and it has therefore seemed advisable to examine all the evidence thus far collected which bears on this question.

## 2.—Means of Distinguishing Intrusions and Extrusions.

Our belief is that the eastern traps are extrusive sheets, which were poured over the floor of the Triassic estuary from various and undiscovered vents at several times during the deposition of the bedded members of the formation; that three of the sheets attained areas of many square miles, — perhaps of several hundred square miles, — the second of the three being the sheet now seen in the main line of ridges from Branford northward to Meriden and beyond to the Massachusetts line, while the first and third constitute the anterior and posterior ridges respectively. It is probable, also, that certain other eruptions occurred later, although the outcrops of their flows are not yet well correlated. If such be the facts, we should expect from our knowledge of existing lavas to find many indications of the contemporaneous origin of these sheets. Deposits of ashes and bombs may reveal the locus of eruption. More or less disturbance may have been created in the unconsolidated sediments as the lava flood advanced over them at the bottom of the estuary. Successive flows or intermittent advances of a single flow may have quickly followed one another, forming a composite sheet of lava. While the middle part of a flow would be relatively dense, the upper part would be vesicular, after the fashion of modern flows, and the surface might exhibit the ropy or clinkery character of lava streams. After the eruption, the igneous sheet would be gradually buried by the continued deposit of sediments that settled slowly down in all the cavities and inequalities of the surface, thereby acquiring a stratification in minute accord with all its irregularities. Where the waves and currents of the ancient estuary were strong enough, clinkery fragments may have been moved about on the surface of the sheet from the more exposed situations, and carried to the deeper, quieter water, there settling down with finer detritus from a more distant source.

On the other hand, if the lava sheets that we have pictured as extrusive were in reality intrusive, nearly every feature would be changed. The contrasted features of the two kinds of sheets must surely be distinct enough for preservation and detection. We have therefore

searched the region carefully for all the outcrops and openings that might give opportunity of testing these deductive possibilities, and we now present the result of this search.

During the progress of our field and laboratory studies, the latter having been carried on by the junior author, we have looked for the results of similar studies in other regions. It appears from this that the question as to the intrusive or extrusive origin of lava sheets is seldom discussed in detail; as a rule, it has been settled by the citation of a few facts, without going through the greater labor of making complete diagnoses. We cannot therefore always determine whether all the criteria of intrusion or extrusion are present in the examples referred to. Opportunity for observation is often limited; search for outcrops is frequently hasty; but the criteria that are cited are as a rule distinctive. Putting all these together, we find that the facts indicative of an intrusion are as follows:—

An intrusive sheet is not confined to a single horizon, but may break across the adjacent strata.

The lower and upper portions of an intrusion are nearly identical. Offshoots may traverse the superincumbent beds for some distance from the main sheet.

The texture of the mass is, with small exception, dense throughout, being uniformly and coarsely holocrystalline in the middle, but becoming very close-grained and glassy close to the upper and lower surfaces, with the development of marked porphyritic structure and of minerals not observable in the middle, and non-polarizing action immediately at the contact.

A cellular or amygdaloidal texture is rarely developed, and when occurring seems to be confined to the upper portion of the sheet. The microscope generally does not discover a definite boundary or a tangential arrangement of feldspar crystals around the walls of these pseud-amygdules, and their cavities are therefore ascribed to replacement.

The porphyritic crystals of the upper surface are arranged tangentially to the inequalities of the enclosing rock, showing the former to be secondary to the latter.

Enclosed fragments of the country rock may be found near the upper, as well as near the lower, surface of the sheet.

The overlying rocks, as well as the underlying, are fractured and disturbed, and friction breccias are sometimes formed along the contact surfaces, the fragments from the intruded and the enclosing rocks being mutually and mechanically commingled.

The beds above the sheet, as well as below, may be altered by heat. The alteration is commonly seen in change of color, induration, production of new minerals, or the development of a local prismatic habit.

Strongly contrasted with all these are the features characteristic of extrusions :—

An extrusive sheet lies conformably on the surface over which it was poured.

The lower and upper portions are strongly unlike.

The upper surface sometimes manifests a ropy flow structure, and sometimes consists of a mass of clinkers.

Vesicular or amygdaloidal texture is very common, especially near the upper surface, and sometimes within the mass.

A composite structure, as of two or more flows, is not uncommon.

Vesicles are often drawn out in a common direction, parallel to the adjacent surface, and indicative of motion; but greatly elongated "spike" amygdulæ stand at right angles to the neighboring surfaces. These amygdulæ are commonly characterized by a definite boundary, and by a tendency to an arrangement of the adjacent feldspar crystals parallel to their walls, and are therefore regarded as the product of expanding gases. Pseud-amygdaloidal cavities are also common.

There is a marked tendency to the development of a porphyritic structure throughout the whole mass.

The overlying beds show no evidence of alteration by heat.

The overlying sediments are arranged conformably with the upper surface of the sheet; open vesicles and the spaces between clinkers are more or less completely filled with sediments, deposited conformably with the surface on which they rest.

A stratified mixture of clastic materials and trap fragments, the latter more or less water-worn, overlies the sheet.

Extrusive sheets may be associated with ash beds and volcanic bombs, and with beds of volcanic conglomerate, more or less water-worn, in a horizon nearly continuous with the lava sheet.

It may be added, that the effects of heat and of mechanical disturbance in the underlying beds are features common to sheets of either intrusive or extrusive origin; and that absence of induration and apparently complete conformability with adjacent beds cannot be taken as proving extrusion.

Induration is one of the most commonly quoted effects of the action



of igneous masses on adjacent sedimentaries. Percival makes frequent reference to it in his Report on the Geology of Connecticut. Yet, of all the above mentioned signs of intrusive sheets, it is perhaps the most difficult one to recognize. Simple induration is easily enough determined with a hammer; but it is another thing to decide whether it results from well advanced cementation by minute deposits of calcite or quartz brought by infiltrating waters, or from baking by heat. The sandstone overlying Saltonstall or Pond Mountain at its northern end is excessively hard; but its hardness is due to secondary deposits of calcite, and not in the least to fusion or baking. Moreover, it frequently happens that the beds overlying undoubted intrusions or adjoining dikes are not hardened: this is commonly the case with sandstones, as, for example, on the back of Gaylord's Mountain. Shales are more affected by a dehydration of their clayey constituents, new minerals being formed when the temperature is higher and water abundant. Sections cut from ordinary biscuit-ware show under the microscope no essential difference from the hydrous kaolinite from which the ware was made, excepting a greater compactness. The argillites of Somerville, Mass., manifest little local alteration near their abundant dikes; as if the general metamorphic process which changed the original clay-beds into argillite had been so complete that the comparatively slight local influence of the dikes was not sufficient to carry the change any further. The argillites of Quincy, Mass., contain small garnets close to the large intrusions of the Blue Hills. The shales overlying the Palisade Range have been changed in color and texture so as to resemble hornstone; biotite, hornblende, and epidote have been locally developed.

The induration of the sedimentary rocks immediately overlying the trap sheets has not been neglected in the study of the ridges; but while simple induration is associated in some cases with unquestionable signs of intrusion, it is found in other cases with equally decisive indications of extrusion, and we have therefore been driven to the belief that mere induration is by no means of constant occurrence or definite association, and that it must be regarded as of little determinative value, at least for the Connecticut eruptives.

Our search for evidence of the origin of the trap sheets has been carried from the coast of the Sound, by New Haven and Branford, along the greater part of the various trap ridges, to Cook's Gap, west of New Britain. Attention has been given chiefly to the back of the sheets, for the upper contacts are much more significant than the lower; but, although the upper contact lines must altogether amount to one or two

hundred miles in length, the number of exposures upon them is very small. Upper contacts are generally found in streams that descend the back of the ridges, and these have therefore been examined most carefully. The list below embraces all that we have yet discovered. The localities are numbered to correspond with the figures on the map of Plate I., and are arranged according to the sheet to which we suppose them to belong, beginning with the trap range near the western border of the formation, and proceeding with the anterior, main, and posterior sheets farther east; these being interpreted as has been explained in earlier articles.<sup>1</sup> Some specimens from the Palisade Range of New Jersey, collected in 1883, are described with those from the western range of the Connecticut Triassic. The several smaller ridges, not correlated with any of the sheets above named, have not been closely examined, and are not here referred to, except in locality 26. The pages in Percival's Report on the Geology of the State, where he describes the localities here mentioned, are added to our list, for the sake of convenient reference. Our descriptions are made as concise as possible, in order to shorten the necessary repetitions; several of the more interesting and instructive localities are given more space in special accounts further on. Mention is made in certain cases of peculiarities of structure that do not bear directly on the question under investigation, partly in order that observations might not be lost, and also in the hope that the details thus collected might in time lead to new generalizations. Certain microscopical variations in the trap naturally resulting from differences in the conditions of solidification are added to those which have a direct bearing on the question of origin; not that they are criteria in themselves, but that they have become recognized as commonly accompanying the two kinds of eruption. For example, the occurrence of porphyritic crystals in an eruptive rock does not establish its extrusive origin, but extrusive sheets are notably more porphyritic than those solidifying beneath the surface. So, too, a holocrystalline structure does not warrant us in saying that a rock is undoubtedly intrusive; but intrusives are more frequently holocrystalline and extrusives more frequently glassy.<sup>2</sup> But we have not attempted to give a complete petrographic account of the specimens that have been examined. It seems advisable to postpone this until samples from all the Triassic basins of the Atlantic slope can be studied together.

<sup>1</sup> Seventh Ann. Report U. S. G. S., 1888.

<sup>2</sup> See, on the other hand, the account of recent lavas from Kilauea, in which glass is rare or wholly absent. E. S. Dana, Amer. Journ. Science, XXXVII., 1889, p. 461.

### 3.—General Features of Intrusive and Extrusive Sheets in Connecticut.

#### GROUP I. WESTERN RIDGES.

*Locality 1. Section numbers, 85–89. Local name, East Rock. Percival's Report, pp. 395–398. Percival's notation, W. S. I. (1).*

*General Account.*—The southwestern face of this fine mass is well exposed in a strong palisaded cliff on the border of New Haven, below which the underlying sandstones can be seen at several points. The overlying sandstone close to its contact with the trap was found on the northeastern slope, in the woods, about a third way down from the summit. This rock is regarded as a part of the West Rock sheet, from which it is thought to have been separated by a fault; similar faults of smaller throw are supposed to account for the notches in the southeastern extension of East Rock itself.

Sections cut from specimens taken from the upper contact and from four feet below it cannot be distinguished from sections similarly selected from the base of the sheet.

The trap is wanting in vesicles of expansion throughout its mass, and is holocrystalline except at contact with other rocks. Extremely close-grained and glassy at the upper contact, where it shows microscopic flowage parallel to surface of junction with the overlying sandstone. Sandstone directly above does not contain fragments of trap; hand specimens appear much more dense than from beds distant from the trap sheet.

*Locality 2. West Rock. Percival's Report, pp. 394–396. Percival's notation, W. S. I. (4).*

The general features of this ridge are like those of East Rock; but no exposure of the upper contact has been found on its back. As far as seen, it is of dense texture, even in the uppermost parts exposed. The southern end of the ridge, where the underlying sandstone is quarried and exposed in contact with the trap, may be reached by the West Haven horse cars from New Haven; the remainder of the ridge is wooded and less easily examined.

*Locality 3. Section numbers, 194–199. Gaylord's Mountain, Roaring Brook. Percival's Report, pp. 402–404. Percival's notation, W. S. II.*

Gaylord's Mountain is a slightly dislocated continuation of the West Rock range; on its back, Roaring Brook has cut a picturesque ravine,

well known in the neighborhood and easily reached by a walk of two miles and a half from Cheshire station of the New Haven and Northampton Railroad, or by a less distance from the station of the same name on the Meriden, Waterbury, and Connecticut River Railroad. It gives the only good exposure of the overlying strata known to us on the back of the western trap sheet, and deserves careful examination.

The trap here is without vesicles throughout its mass; holocrystalline except at contact with other rocks; at its upper contact it is extremely fine-grained and glassy; flowage action is seen in the microscopic arrangement of the feldspar prisms parallel to upper line of junction. Upper surface of sheet obliquely traverses the beds of the overlying sandstones and shales; several small offshoots of fine texture extend into the overlying rock (Fig. 12). Pebbly sandstone directly above the sheet does not contain fragments of trap, and is not perceptibly affected by the igneous mass even close to the junction; the shales that elsewhere approach the sheet are apparently indurated. See special account.

*Section numbers, 45-55. Palisade Range, New Jersey.*

The easternmost or lowest trap sheet of the New Jersey Triassic area seems to correspond with the lowest or westernmost sheet of the Connecticut area, and is therefore referred to here in order to extend the number of examples quoted. Its base is finely exposed in contact with the underlying sandstones at the Hamilton-Burr duel ground in Weehawken, on the bank of the Hudson, opposite New York City; this outcrop is well figured in Plate IV. of the Annual Report of the New Jersey Geological Survey for 1882. Other exposures of the underlying sandstone are common up the west bank of the Hudson, but contacts are relatively rare. The only upper contact known is one pointed out some years ago by Professor Cook (*Geology of New Jersey*, 1868, p. 201), in Englewood, about a mile south of the station of that name on the Northern New Jersey Railroad, in a brook channel a few hundred feet west of a road.

The trap of this sheet is dense throughout, as far as examined at numerous outcrops. Its texture is rather coarse in the middle of the sheet, but becomes very fine at lower and upper contacts. The adjacent bedded rocks are distinctly altered from their original condition, with the development of new minerals. No fragments of trap are found in the overlying beds.

Under the microscope the trap is seen to be almost identical with that

from Gaylord's Mountain, but more olivine is present in the holocrystalline portions. Approaching the upper and lower contacts, there is a gradual disappearance of the augite and a decrease in the coarseness of texture; the augite disappears at the contacts, porphyritic crystals of olivine become abundant, and the rock is extremely fine-grained and glassy. Occasional pseud-amygdaloidal areas occur in the trap; but no vesicles due to the expansion of occluded gases have been observed.

## GROUP II. EASTERN TRAP RIDGES.

### DIVISION I. ANTERIOR RIDGES.

*Locality 4.* Section numbers, 26-28. Anterior at northern end of Totoket Mountain. *Percival's Report*, pp. 344, 345. *Percival's notation*, A. 1. N. of E. II.

The ridge anterior to Totoket has few strong outcrops; the one here referred to is at the north end of the main sheet in a stream bank, east of S. W. Loper's, South Durham (Fig. 3). Best reached by stage from New Haven to North Guilford. Base of sheet for a thickness of eight feet consists of a breccia of scoriaceous trap and clastic material, cemented together by quartz and calcite; upper part extremely vesicular; no upper contact found. Lower portion glassy and porphyritic.

*Locality 5.*  $\frac{1}{2}$  mile S. E. of East Meriden. *Percival's Report*, pp. 302-305. *Percival's notation*, A. 1. of E. III. (3).

The anterior to the long Durham range is traceable for many miles, but is often heavily covered with drift. The bluffs of the ridge are of the ordinary dense trap, and its back is as usual vesicular. About a quarter of a mile south of Black Pond, near East Meriden, there is a faint depression in its back, and here the ground is covered with numerous fragments of sandstone containing pieces of vesicular and angular trap (Fig. 13). A shallow opening would secure excellent specimens. It seems as if there was here a depression in the surface of the sheet, into which local fragments of trap were washed with sand from a more distant source.

*Locality 6.* West of northern end of Higby Mountain. *Percival's Report*, pp. 362-365. *Percival's notation*, A. 1. of E. III. (4).

The gap between Higby Mountain and Chauncy Peak is followed by the Meriden, Waterbury, and Connecticut River Railroad, and by the highway from Meriden to Westfield (Fig. 4). A road branches from the latter in the gap, and runs south on the amygdaloidal back of the

anterior ridge. Following it about a third of a mile, and then turning west into the woods, a few ledges are found consisting of ashes and bombs, such as are more fully described under locality 8. Half a mile farther south, the sandstone lying on the back of the highly vesicular trap is exposed in the roadside. Numerous vesicular fragments of trap are included in the sandstone. Clastic deposits are seen in many of the vesicles in these fragments.

*Locality 7. Southwest and west of Chauncy Peak. Percival's Report, p. 364. Percival's notation, A. E. III. (5).*

The road from Meriden to Westfield crosses this anterior ridge about half a mile southwest of Chauncy Peak, and the above-mentioned ash and bomb structure is visible in roadside cuts (Fig. 5, locality 7'). A farm road follows the vesicular back of the ridge to the northwest, and the ledges to the west of it show the same structure again, locality 7.

*Locality 8. Section numbers, 83, 84 a, 209-212. Anterior of Lamentation Mountain. Percival's Report, pp. 265, 266. Percival's notation, A. of E. III. (5).*

The road from Meriden to Berlin follows the base of the ridge anterior to Lamentation Mountain for some distance (Fig. 5). About two miles north of Meriden, a curious bluff of volcanic ashes and bombs is seen in the face of the ridge, locality 8. The underlying sandstone is first seen at the foot of the bluff; the overlying sandstone is found by crossing the ridge to its eastern slope, locality 8', passing several trap ledges in the woods on the way.

The trap is underlain by a bed of fine lapilli, about thirty feet thick, containing numerous rounded blocks or bombs of dense trap, from six inches to three feet in diameter; one of these blocks is half imbedded in the underlying sandstone. This basal ash bed is undoubtedly the same as the one mentioned in the two preceding localities, but it is not seen much farther north; half a mile in that direction there is a local trap conglomerate in the same horizon with the anterior sheet; vesicular and water-worn pebbles are here interbedded with sand, as if this point were not far distant from a wave-beaten margin of the anterior lava sheet. The trap of the ridge is frequently cavernous and amygdaloidal, and remarkably so near the upper surface. No local closeness of grain at upper contact; overlying sandstone deposited parallel to inequalities of trap surface; fissures and vesicles near surface filled with sand, connecting upwards with overlying sandstone. Fragments of vesicular trap and abundant grains of water-worn glassy



trap in sandstone at contact ; two thin tufa beds a few feet above trap sheet. See special account.

*Locality 9.* Anterior to Cat Hole Peaks. *Percival's Report*, pp. 375, 376.

Two small openings in the anterior ridge east of the Meriden poorhouse, a mile and a half northwest of the city (Fig. 6), expose the lower part of the sheet. It is generally of dense structure, but presents extremely irregular forms, as if consisting of ropy masses of flowing lava ; the spaces between these masses are filled with a much weathered loose material that may perhaps be lapilli ; there are numerous "spike" amygdules (see special account of locality 13) near and at right angles to the convex surfaces of the lava masses. The upper portion of the same sheet, where seen on roads on the back of the ridge, locality 9', is highly vesicular.

*Locality 10.* Anterior of Notch Mountain. *Percival's Report*, pp. 375, 376. *Percival's notation*, Ant. to E. IV. 1 (3).

A hundred feet southwest of the Meriden poorhouse, the sandstone appears a little above the trap of the anterior sheet to Notch Mountain (Fig. 6) ; a small piece of vesicular trap was found in it. The same anterior sheet, where exposed in the Reservoir Notch, a third of a mile to the west, is extremely vesicular in its upper part.

*Locality 11.* Anterior to Shuttle Meadow Mountain.<sup>1</sup> *Percival's Report*, pp. 375, 376. *Percival's notation*, Ant. to E. IV. 1 (4).

A few poor exposures in the road on the back of this anterior, half a mile south of Shuttle Meadow Reservoir, reveal weathered fragments of vesicular trap in the sandstone overlying the sheet. Some of the vesicles in these fragments contain clastic deposits.

*Locality 12.* Anterior to Farmington Mountain. *Percival's Report*, pp. 375. *Percival's notation*, Ant. to E. IV. 1 (9).

An excellent exposure of this anterior is found about a mile east of Farmington, directly north of Stetson's house (Fig. 7). Middle of sheet dense ; bottom sparingly cavernous ; upper portion generally sub-amygdaloidal to cavernous ; very vesicular at upper surface, where numerous vesicles are filled with indurated bitumen ;<sup>2</sup> surface of sheet very uneven, with sandstone conformably filling hollows and open vesicles ; intimate mixture of trap fragments and sand grains on upper surface.

<sup>1</sup> Called "North High Rock" in Bull. Mus. Comp. Zool., 1889, No. 4, Fig. 13.

<sup>2</sup> Percival, Geol. Conn., 1842, p. 375.



*Locality 13. Section numbers, 175-182 b. Farmington River Gap, Tariffville. Percival's Report, pp. 391, 393. Percival's notation, A. to E. IV. 2 (2).*

The main and anterior ridges are traversed by the Farmington River at Tariffville (Fig. 8); the Connecticut Western Railroad passes through the gap and exposes the complex structure and the upper surface of the anterior ridge in a long cut a quarter of a mile east of the village. The upper surface is seen again on the east bank of the river, just above the road bridge.<sup>1</sup>

A double sheet, as if of two flows. Lower sheet generally dense; sub-amygdaloidal, very porphyritic and glassy toward upper surface; upper portion very vesicular, and near surface contains "spike" amygdules. No local close grain in trap at top of sheet; sand grains conformably stratified in vesicles and small irregularities of surface; mixture of large and small fragments of trap with sand over surface, this mixture passing laterally into a tufa bed; trap fragments often rounded as if water-worn.

Upper sheet compact at the base; sub-amygdaloidal and vesicular in upper portion; generally very porphyritic and originally possessing a glassy base; overlying sandstone not seen in railroad cut, but well shown on opposite river bank below, locality 13', where it carries numerous trap fragments. See special account.

#### DIVISION II. — MAIN RIDGES.

*Locality 14. Section numbers, 1-4, 73, 76. Saltonstall Mountain. Percival's Report, pp. 323, 324. Percival's notation, E. I.*

Saltonstall or Pond Mountain is the southernmost member of the eastern main trap range; it forms a well marked crescentic curve, with Saltonstall Lake lying along the inner side. An under contact, locality 14', is found in the cut of the Shore Line Railroad, a quarter of a mile east of Fair Haven station, and an upper contact is almost revealed at the eastern end of the same cut. The back of the sheet is very scoriaceous all along the shore of the lake, but no upper contact is found until the northeastern end of the ridge is nearly reached, when it is exposed in a little gully in the woods on the back of the sheet over a pasture, locality 14 (Fig. 2).

The trap is porphyritic and was originally glassy; at lower contact with sandstone, the trap is brecciated, fine-grained, and glassy; slightly vesicular; vesicles elongated, indicating flowage action. Very vesicular

<sup>1</sup> W. North Rice, Amer. Journ. Science, XXXII, 1886, pp. 420-423.

and irregular texture near its upper surface ; stratification of sandstone conformable to irregularities in the upper surface. Intimate mixture of sand grains and trap fragments along and above line of junction ; surface fissures and vesicles filled from above with sand grains, distinctly stratified parallel with the sandstone bed above. The hardness of the overlying sandstone is due to induration by infiltrated calcite, etc., and presents no evidence of being derived from baking by heat. See special account.

*Localities 15, 16. Section numbers, 5-17, 77. Totoket Mountain, inside south and north hooks. Percival's Report, pp. 336-338. Percival's notation, E. II.*

Totoket Mountain is a well formed crescent, next north of Saltonstall Mountain. Exposures of the upper contact with the sandstone were found in a stream, locality 15 (Fig. 2), half a mile northwest of North Branford, in the southern hook of the crescent ; and again in a stream-bed inside of the northern hook, locality 16 (Fig. 3). Another stream, a mile southwest of the last, locality 16', cuts a channel in what seems to be a bed of clinkers.

The trap is porphyritic, and originally possessed a glassy base ; upper surface very vesicular and irregular ; sandstone lamination conformable to uneven contours of surface ; intimate mixture of rounded (water-worn) trap grains and sands at contact ; occasional trap fragments in sandstone for a few feet above ; clastic grains of trap, quartz, etc., fill vesicles, with lines of deposition parallel to the stratification of the sandstone above ; sand in vesicles is connected with the sandstone above by narrow necks. The overlying sandstone, locality 16, is indurated by cementation, and shows no signs of baking.

*Locality 17. Section numbers, 204-207. Higby Mountain. Percival's Report, p. 351. Percival's notation, E. III. (4).*

The eastern base of Higby Mountain, south of the road from Meriden to Middlefield, is followed by the upper course of Fall Brook, which at a point about a quarter of a mile south of the road lays bare a valuable exposure of sandstone lying on the trap, locality 17 (Fig. 4). A second exposure is found a little farther south, locality 17'. Numerous fragments of vesicular trap enclosed in sandstone are found in the stream for some distance northward.

The trap is porphyritic, and originally glassy ; upper surface very vesicular, much decomposed, and uneven ; not excessively fine-grained at

upper contact. Sand grains fill vesicles and irregularities of surface, conforming closely to their shape; intermixture of sand and numerous large and small trap fragments along line of junction; occasional rounded (water-worn) fragments of amygdaloidal trap even five feet above trap sheet.

*Locality 18. Section numbers, 132-134. Lamentation Mountain. Percival's Report, pp. 351, 352. Percival's notation, E. III. (5).*

A road passes the north end of Lamentation Mountain and bridges Spruce Creek, that flows northward from the back of the mountain. Exposures of sandstone on the trap are found up and down stream from the bridge; the best locality is about an eighth of a mile up stream, south (Fig. 10), where the exposure is of much interest.

Trap porphyritic and glassy, particularly at upper surface; upper contact not locally of close texture; upper portion of irregular texture, highly vesicular, with uneven, rolling surface; sand grains fill fissures and vesicles near surface of trap; narrow necks filled with the same clastic material connect these vesicles with the sandstone above; intimate and complicated mixture of sand and trap over the upper surface (Fig. 15); stratification of sand in vesicles and above sheet conformable to surface, and generally parallel.

Water-worn fragments of vesicular trap occur in sandstone for two or three feet above surface of sheet. The vesicles in these fragments often contain small particles of trap mixed with quartz and muscovite grains.

*Locality 19. Section numbers, 136-150. Meriden City Quarry. Percival's Report, pp. 370, 371. Percival's notation, E. IV. 1 (1).*

The small easternmost ridge of the Hanging Hills group (Fig. 5 or 6) has been deeply quarried for railroad ballast and road metal at its southern end, and now presents an excellent dissection of a complex trap sheet, — the most instructive quarry in the region. It is about a mile north from the centre of Meriden. The trap of the quarry consists of a lower and an upper portion, separated by a well defined surface, inclined to the eastward with the general dip of the Triassic monocline. The lower sheet is exposed for about ten feet below the surface of separation; the upper, for sixty or eighty feet above it. Lower sheet extremely porphyritic, vesicular, and glassy; upper part scoriaceous, of rolling, ropy surface, showing evidence of normal weathering previous to quarrying. A small amount of foreign clastic material occurs mixed

with scoriæ at contact with upper sheet. No local close-grained texture at upper contact.

Upper sheet dense as far as exposed in quarry; becomes somewhat fine-textured at contact with lower sheet; its original upper surface not seen in the quarry, but half a mile northeastward on the east side of the ridge, locality 19' (Fig. 6), the trap becomes vesicular. Several lines of fault breccia traverse the quarry, consisting of large and small angular fragments of trap contained in apparently unstratified sandstone; often slickensided; the trend of these breccias agrees with that of the neighboring faults, as determined by stratigraphic evidence. See special account.

No other significant exposures of the main sheet have yet been found in its further northward extension in Connecticut.

#### DIVISION III. POSTERIOR RIDGES.

*Locality 20. Section numbers, 34-37, 74, 75. First ridge posterior to Saltonstall Mountain. Percival's Report, p. 324. Percival's notation, P. 1, E. I.*

The upper surface of this posterior ridge is exposed only near its northeastern end, at a road crossing, about a mile northeast of Saltonstall Pond (Fig. 11). Elsewhere the outcrops are generally dense, but sometimes vesicular on the back of the ridge.

Upper portion of sheet very vesicular and glassy; not locally close-grained at junction with overlying sandstone; sand grains and trap fragments occur together at upper contact; sand fills vesicles in trap; occasional water-worn fragments of trap in the sandstone a foot or more above the sheet; base of sheet sub-amygdaloidal.

Ridges of very coarse trap conglomerate occur in the neighborhood, but their relation to this sheet is not yet clearly made out.

*Locality 21. Section number, 18-23, 187-193. Second ridge posterior to Saltonstall Mountain. Percival's Report, p. 325. Percival's notation, P. 2, E. I.*

According to our interpretation of the stratigraphy, this ridge is a second outcrop of the sheet already seen in the first posterior, here showing a western dip, as if on the eastern side of a synclinal; its base is open in several small abandoned quarries near a road crossing, half a mile northwest of Branford station, Shore Line Railroad, locality 21 (Fig. 11); and its upper surface, with something of the overlying sandstone, is seen an eighth of a mile north of these quarries, on the eastern

side of a small pond, locality 21'. The great fault that uplifts the crystallines on the eastern border of the Triassic formation passes close to the southeast of this ridge, and is probably the cause of the reversed dip of its sheet and of the local fracture and overturning that it exhibits.<sup>1</sup> Trap generally porphyritic and glassy; dense at the lower contact; several exposures of fault breccia with the sandstone (Fig. 17); trap sends minute tongues of pure glass into lower sandstone, and occasionally encloses grains of quartz and feldspar. Highly cellular at upper surface on northwestern slope; its junction with sandstone above is not marked by local close texture; sandstone immediately above contains numerous fragments of vesicular trap; intercalated beds of shale and trappy conglomerate occur near base of sheet.

*Locality 22. Section numbers, 31-33, 40, 73, 78. Ridge near Middlefield Station, Air Line Railroad. Percival's Report, pp. 355, 356. Percival's notation, P. 2 (S), E. III. (3).*

This posterior is traceable for several miles on the east of Durham Mountain, but the only satisfactory exposure is in a railroad cut, a little way west from Middlefield station, Air Line Railroad. Base of sheet sub-amygdaloidal as a whole, and locally very vesicular and uneven; subordinate intercalated layers of trappy shale and irregular masses of abundantly vesicular trap near base; some vesicles filled with elastic grains of quartz, feldspar, muscovite, and fragments of glassy trap. Upper surface very vesicular. Trap generally glassy and porphyritic.

*Locality 23. Section numbers, 24, 25, 72. Falls of the Aramamit River. Percival's Report, pp. 354, 355. Percival's notation, P. 2 (N), E. III. (4).*

This is probably on the same posterior ridge as the preceding, although its direct connection has not been traced. Rock Falls Station of the Air Line Railroad is close by (Fig. 9). Trap generally glassy and porphyritic, and not locally close-grained at junction with overlying rock. Upper surface extremely vesicular, with many vesicles filled with elastic material connecting with the main mass of sandstone above by narrow necks. Trap grains mixed with trap fragments at contact and for several inches above. A beautifully water-worn pebble of trap was found imbedded in the sandstone several feet above the sheet. Drift boulders in railroad cut near by show contacts and mixture of trap and sandstone.

<sup>1</sup> Amer. Journ. Science, XXXII., 1886, p. 347; Bull. Museum Comp. Zool., Geol. Series, II., 1889, p. 72.

*Locality 24. Section numbers, 120-123. Highland Lake. Percival's Report, pp. 336-338. Percival's notation, P. 4, E. III. (5).*

The ridge posterior to Chauncy Peak is cut near its southern end by the Meriden, Waterbury, and Connecticut River Railroad, a quarter of a mile east of Highland station (Fig. 4). An excellent exposure. Under contact not shown. Trap generally dense; originally glassy and porphyritic; not locally close-grained at upper contact; upper portion extremely vesicular; sand grains filling vesicles and fissures, their lines of deposit conforming to the irregularities of the trap surface (Fig. 14); these deposits connected with the sandstone above by necks; inequalities in upper surface of trap covered by conformably stratified sandstone. Numerous angular, vesicular, large and small fragments of trap lying above the sheet; spaces between these filled with irregularly but conformably stratified sandstone; vesicles in fragments filled with sand; some of the vesicles only partly filled, and in such cases the upper surface of the filling is parallel to the dip of the Triassic monocline.

*Locality 25. Section numbers, 124-131. Hartford Ave. and N. Stanley St., New Britain. Percival's Report, pp. 381, 384. Percival's notation, P. (e), E. IV. I. (7).*

The overlapping ends of the small trap ridges on the northeastern border of New Britain are regarded as faulted portions of a single posterior sheet; a small stream flows between them. The eastern ridge is quarried, and discloses the base of the sheet; the upper contact is found where the stream runs on the back of the western ridge.

Trap generally dense, but containing local amygdaloidal areas, surrounded by dense trap, as if produced by intermittent flowing; very vesicular at upper surface, and originally possessing a glassy base; sandstone immediately above contains water-worn grains and fragments of much decomposed trap.

*Locality 26. Section numbers, 152-156. Near Trinity College, Hartford. Percival's Report, pp. 385, 386. Percival's notation, P. (f), E. IV. I. (9).*

This ridge is of doubtful relationship: it may be a second posterior sheet, and therefore not directly comparable with the previous examples. Its middle portion and base are well exposed in large quarries. The trap is generally dense; triangular areas between the feldspars contain a little glass; the lower portion is brecciated and extremely scoriaceous; obsidian-like grains of trap in shale immediately under trap; upper portion vesicular, but overlying sandstones not seen. See special account.



#### 4.—Special Accounts of the more important Localities.

The following more extended descriptions of certain selected localities are added, to give a better understanding of the fulness of evidence on the question in discussion than could be obtained from the foregoing summary. We thus present examples of what we interpret as an intrusive sheet at Roaring Brook, on Gaylord's Mountain; a bed of volcanic ashes and bombs, presumably near the locus of eruption of one of the extrusive sheets, in the anterior ridge of Lamentation Mountain; the base of an extrusive sheet, at Hartford; the top of an extrusive sheet in Saltonstall Mountain; and extrusions of complex structure at Meriden and Tariffville.

*Roaring Brook, Gaylord's Mountain. Locality 3.*—On entering the ravine of Roaring Brook from the drift plain at the eastern foot of Gaylord's Mountain, outcrops of sandstone are soon encountered with dip of  $40^{\circ}$  to the eastward. These are followed for several hundred feet up stream until the rock in the stream bed is found to consist of fine-grained trap, the line of contact having been passed unnoticed. A little search is needed to discover it, but when once made out it can be followed with some distinctness. In a general way, the trap sheet thus disclosed lies parallel with the beds above it, but on tracing its surface up the ravine, it is seen to depart significantly from perfect parallelism and comes in contact successively with different beds. Moreover, it gives forth very distinct branches or leaders (Fig. 12), one of which extends for twenty feet into the overlying strata. The margins of these offshoots, as well as the edge of the sheet itself, are tolerably even, in marked contrast with the excessive irregularity of the upper surface of the trap sheets of the eastern ranges. The overlying beds give not the least sign of trap fragments which so generally characterize the beds lying on the back of the eastern sheets. Taking all these features together, and placing them in contrast with those of the sheets on the eastern side of the valley, there can be no question that their consistent differences are due to some fundamental difference in the manner of eruption of the lava. We are forced to the conclusion, that the western sheet has been driven in between the previously deposited beds of sandstone and shale, while the others have been poured out on the surface of certain beds, and afterwards buried under others of later date. Study with the microscope confirms this conclusion. The trap of West Rock, a continuation of Gaylord's Mountain to the south, has been described petro-



graphically by Hawes, and classed by him as a dolerite.<sup>1</sup> Sections from near the middle part of the trap sheet forming Gaylord's Mountain do not appear to differ materially in their microscopic characters from those of West Rock. The trap is holocrystalline far from its upper and lower junction with the sandstone or shales, and, as has been pointed out by Hawes, is much less altered, and contains fewer hydrated minerals, the products of decomposition of the augite, feldspar, etc., than the eruptive masses forming Saltonstall Mountain, or the Durham range, to the east. Hawes believed this difference to be connected with geographical location, and thought it had nothing to do with geological age.<sup>2</sup> According to J. D. Dana,<sup>3</sup> the great alteration of the trap in the eastern range took place at the time of ejection, and depended on the encountering of subterranean waters which the molten rock took up in its passage through the sandstone strata. Hawes followed this view, and thought the eruptive magma might in such a way assume the diabase type, while under less humid conditions the same magma on consolidating would form a dolerite.

It appears, however, that the difference in the hydration of the eastern and western traps can be better accounted for by original structural and mineralogical differences incident to the very different conditions under which the several trap sheets solidified. This will be referred to again in the special account of Saltonstall Mountain.

In the trap from Gaylord's Mountain, on approaching the overlying sandstone, there is a gradual fining of the texture and an increased tendency towards a porphyritic structure, the porphyritic crystals there being set in an undifferentiated, non-polarizing base. The augite occurs more rarely in well-outlined individuals, and constantly tends towards a granular structure. Olivine, which has been detected in minute grains in the same rock to the south, has once been abundant at the Roaring Brook contact, in well-outlined porphyritic crystals, but is now mostly altered to a fibrous grass-green to yellowish-green serpentine, or entirely replaced by pseudomorphous calcite or dolomite. The augite occurs less and less plentifully upwards, and at two inches from the junction with the sandstone it cannot be found even in grains. Accompanying the loss of augite and the increase of olivine, there is, especially at the contact, a development of a non-polarizing base in which are scattered innumerable acicular ledges of feldspar, some porphyritic, showing an

<sup>1</sup> Amer. Journ. Science, IX., 1875, p. 186.

<sup>2</sup> Ibid., p. 190.

<sup>3</sup> Ibid., VI., 1873, p. 107

arrangement parallel to the adjacent surface of the sandstone. The glassy base with its accompanying dots of ferrite is best shown in sections from the narrow leaders running into the overlying sandstone (Fig. 12). These leaders penetrate the sandstone for a distance of several feet; the largest, which is three inches wide at its beginning and over twenty feet long, is seen under the microscope to be nearly pure glass, in which minute double refracting areas are abundant; the smallest leaders are mere threads, and in composition are essentially glass.

Although as a whole the western trap is little changed, marked alteration and hydration are shown in the upper surface of the trap of Gaylord's Mountain, and in the leaders; and it is to be noticed in connection with the much greater hydration of the Saltonstall range, that this zone of glassy trap corresponds to the general glassy base of the extrusive sheets. By the association of the intrusive trap at Roaring Brook with the coarse sandstone immediately above, it has probably been brought into contact with water to a greater or less extent, and part of its alteration may be attributable to this cause. No amygdulæ occur in the trap, except rarely one of a pseud-amygdaloidal character; there is no tendency towards a mixture of the two rocks along the line of junction, either of the kind seen above the extrusions or like the breccias known with certain intrusions.

The microscope affords no evidence that the conglomeratic sandstone has been indurated by heat. The sandstone is much decomposed, owing to alteration of its feldspathic constituents, and its grains are somewhat incoherent. This failure to show induration does not, however, militate against the intrusive origin of the trap. Similar sandstone at the base of Saltonstall Mountain exhibits no greater evidence of heat induration, although it was surely subjected to a high temperature.

As far as both microscopical and field evidence go, there can be no doubt that in the case of Gaylord's Mountain we have a well marked example of an intrusive sheet. No observers have given it a different interpretation.

*The Ash-bed in the Lamentation Anterior. Locality 8 (Fig. 5).* — Two miles north of Meriden, near the road leading to New Britain, the following section is exposed in the ridge anterior to Lamentation Mountain. The base of the bluff on the upper slope of the ridge shows a small outcrop of fine-grained, brownish red sandstone; immediately above this there are twenty or more feet of tufa-like material, containing oval and discoidal areas of close-grained trap that we have interpreted as volcanic

bombs. Above the tufaceous deposit is a sheet of very amygdaloidal trap, overlain by a dark pinkish gray sandstone, carrying two thin subordinate layers of trappy material a few feet over the contact. In the hand specimen and under the microscope, this sandstone appears identical with the fine matrix of a trap conglomerate noted by Percival as occurring half a mile to the north, and presumably forming the stratigraphical equivalent of the tufaceous deposit at this point. The sequence of outcrops here disclosed is one of the most valuable that it has been our fortune to discover, and has attracted much local attention since it was found in the spring of 1887. It will well repay attentive examination. The following account refers in greater part to its microscopic structures.

Under the microscope the material of the bluff enclosing the volcanic bombs is found to be made up of small fragments of trap, generally very fine-grained and much altered. Small greenish brown areas dotted thickly with ferrite are non-polarizing as a whole; these appear to be volcanic glass. A few porphyritic ledges of plagioclase occur in them. Most of the eruptive grains have been altered to chlorite and quartz, and are intimately mixed with granular calcite. The microscope fails to discover any grains of water-worn quartz or other elastic material, although it is probable that more or less normally deposited sediment occurs thinly scattered through the mass. No stratified arrangement of the trap grains is noticeable in the microscopic sections, except an orientation of chlorite plates parallel to the stratification of the sandstone on the back of the ridge, and to a rude lamination brought to sight in the face of the tufaceous bed by weathering. Following Geikie, this bed would be called a tufa, consisting of a shower of lapilli. It appears to have been deposited rather rapidly in a body of water, and probably at no great distance from a point of eruption, as it soon disappears to the north and west. It is traceable a mile and a half to the southeast, in localities 6 and 7.

The volcanic bombs occurring with the lapilli give the face of the bluff a curious mottled appearance. They show no definite arrangement, but are more numerous near the bottom of the bed, where one of them seems to have imbedded itself in the underlying sandstone; they are remarkable for their non-vesicular character and their compact uniform texture from the centre to the surface. The microscope detects no variation in texture in any part except that due to a partial alteration of the surface. It shows them to be extremely close-grained, with porphyritic crystals of augite set in a ground mass of minute plagioclase

needles and brownish glass. As regards their origin the microscopic study yields no solution, but the field evidence leaves little doubt in the observer's mind. The thin trap sheet overlying the lapilli is, wherever observed at this locality, more or less vesicular, and in many places cavernous. The greatest vesicularity is at its upper surface, and in the hand specimens from the contact with the sandstone above the sand is seen to have minutely penetrated the cavities and fissures of the scoriaeous amygdaloid. The sand grains not only occupy surface vesicles, but they have percolated along cracks and irregularities in the trap to a depth of two feet below the surface; in some cases, they apparently lie between or surround large areas of amygdaloid. Irving speaks of similar phenomena in connection with the upper surfaces of extrusions in the Lake Superior region, and refers to them as sandstone "veins."<sup>1</sup> The lamination of the overlying sandstone is parallel to the surface of the trap, conforming closely to its minor irregularities. Flowage action is seen in the trap in the elongation of its vesicles.

An interesting point is the occurrence of two thin layers of tufa in the sandstone just above the trap, each about an inch in thickness and about a foot apart. These layers appear in the hand specimen of a rusty brown color, composed of water-worn fragments of trap mixed with elastic quartz, and have a much weathered appearance. Under the microscope their tufaceous character is well shown; vesicular porphyritic trap grains abound, and others of non-polarizing character are derived from yellowish glass, now partially or wholly devitrified. Mixed with the trap fragments, there are abundant grains of quartz, muscovite, and orthoclase, probably derived from the crystalline rocks which surround the Triassic formation. The tufas as well as the sandstone effervesce readily with dilute hydrochloric acid, owing to the presence of secondary calcite. The sandstone owes its dark color in a large part to the presence of comminuted dust-like particles of extremely weathered trap, scattered through it and now altered to earthy chlorite and fine dots of ferrite.

The several well-marked features of this interesting locality leave no doubt that the trap sheet here is of extrusive origin.

*Hartford City Quarry. Locality 26.*—One of the posterior sheets, as yet not safely correlated with other outcrops, forms a ridge of moderate height, with strong western bluff, in the southern part of Hartford, where it is extensively quarried for road material. Trinity College stands on its eastern slope.

<sup>1</sup> Copper-Bearing Rocks of Lake Superior, Monogr. V., U. S. G. S., 1883, p. 292.

The upper portion of the sheet is vesicular, but its upper contact is not seen. The under contact is well revealed in the quarry, and affords the best exposure for the study of the base of a sheet that we have yet found. It is of interest also as being the locality described many years ago by the elder Silliman.<sup>1</sup> Yet this particular contact is not altogether characteristic of the under contact of most of the extrusive sheets, for as a rule the junction of the trap with the shale is without complication of any kind: one lies smoothly on the undisturbed surface of the other.

The underlying shale of the quarry will be first considered. Four inches below the trap, the shale locally consists of tufaceous material. Round and linear fragments of yellowish brown glass are seen under the microscope, thickly sprinkled with minute particles of some decomposition product of iron. These partially devitrified glassy areas are undoubtedly the remains of obsidian-like fragments deposited as the normal result of erosion from some volcanic flow, or as ejected matter from a volcanic vent. In either case, volcanic vents sent forth showers of ashes or flows of lava, presumably at no great distance from this point, and at the time of the deposition of the sandstone.

The contact line between the bottom of the trap and the underlying shale is as a rule irregular and indistinct. The lower portion of the trap for a distance of four feet presents a very vesicular and scoriaceous appearance, not unlike the upper surface of the lower flow exposed in the Meriden Quarry. The microscope shows portions of this scoriaceous material thickly sprinkled with well marked gas cavities, many of them having a linear arrangement, roughly parallel to the upper surface of the shale, due to the flowing action of the trap while in a viscous condition. The same parallelism is also well shown at the upper surface of the first flow in the Meriden Quarry, locality 19.

The trap for a thickness of several feet is not only abnormally scoriaceous, but is extremely broken. Irregular and rounded areas of vesicular trap are apparently cemented together by brown calcareous sandstone possessing a lamination generally parallel to the stratification of the shale below. The microscope shows these brown areas to be mixtures of secondary quartz, calcite, and a little chlorite, arranged in layers; they must have been deposited by infiltrating waters. The texture of the trap gradually increases in coarseness as we approach the central part of the sheet, and then grows porphyritic and finer-grained near the upper surface. Careful search has failed to discover its upper surface in

<sup>1</sup> Amer. Journ. Science, XVII., 1829, pp. 121-132.

contact with shale or sandstone on the eastern slope of the ridge, but it is generally very vesicular, and resembles in all particulars the upper surfaces of all the well determined extrusions in the valley.

If the abnormal scoriaceousness and broken character of the under surface of the trap be rightly interpreted as a result of the flowing beneath water, then its anomalous character, as compared with the lower contacts of numerous other extrusives in the valleys, remains to be explained. We have little direct evidence on this point, but conclude, as sufficient heat and moisture to form a scoriaceous texture at the bottom of the flows were present in all cases, that some other factor must determine the variation between the considerable disturbance manifested here and the lack of disturbance at the contact of sand beds and the base of flows in other localities. The most available additional factor is a variation of pressure, and this would be a minimum at the base of a thin flow in shallow water. The Hartford sheet is probably not over forty feet in thickness. Emerson has described a similar disturbance and brecciation at the base of a rather thin flow in Massachusetts. It may therefore be the case that thin lava flows in shallow waters develop an unusually scoriaceous structure at their base as they advance.

*Saltonstall Mountain. Localities 14 (Fig. 2) and 14'.—*The curved outline of this ridge seems to be the result of a gentle folding after the sheet had taken its place in the bedded series, rather than a consequence of conditions attending the time of eruption; the same may be said of the larger and somewhat more irregular curve of Totoket Mountain, next to the north. There is an almost intuitive hesitation before the suggestion that anything so massive as a lava sheet could be folded, but this must disappear on recalling the strong folds of the heavy sandstones of Pennsylvania, or the stupendous contortions of the gneissic rocks on which the Triassic formation rests. If the sheet were intrusive, it might, to be sure, have wedged its way in between the sedimentary beds after they had been tilted and gently folded, thus accepting their guidance as to the form its outcrop should present; and this has been currently believed, both here and in the case of the similar but larger curves of the trap ridges in New Jersey. It is therefore of more than local importance to determine whether the Saltonstall sheet is an intrusion or an extrusion; for if the latter, it surely cannot have originally taken its present form, but must have passively suffered deformation from an initial horizontal attitude.

The small opportunity for observation of the contacts of this sheet



with the adjacent beds has already been mentioned. The base is seen in the Shore Line Railroad cut, locality 14'. The back of the sheet has been carefully searched from one end to the other with no success except in the little gully in its northern hook, locality 14 (Fig. 2), but the general uneven and scoriaceous texture of its upper portion is continuously visible for two miles or more as it dips under Saltonstall Lake; this is seen to best advantage by rowing along the shore in a boat, which may be obtained at the southern end of the lake.

The base of the trap sheet for a distance of several feet is decidedly amygdaloidal and close-grained; and, owing to its broken character and the subsequent infiltration of secondary quartz and calcite, it locally resembles a breccia. Under the microscope, the trap is seen to be very amygdaloidal, and the vesicles are elongated by the flowing of the trap conformably to the line of junction with the sandstone below. Specimens of this breccia-like mass appear identical to the eye and under the microscope with those from the base of the anterior at the north end of Totoket Mountain, locality 4.

Round areas of a brownish material resembling water-worn fragments of sandstone are apparently enclosed by the trap near its junction with the sandstone, but the microscope shows these to be secondary deposits in vesicles, and to consist of quartz and granular calcite, products of alteration, stained brown by iron. Similar areas are found at the base of a trap ridge on the northeastern limits of New Britain, locality 25, where Percival erroneously refers to them as consisting of dark red jasper, the product of the indurating action of the trap;<sup>1</sup> also at the base of the tufaceous bed of the anterior to Lamination Mountain, locality 8, and at the Hartford City quarries, locality 19. A section of sandstone three inches below the trap sheet of Saltonstall shows water-worn fragments of trap, and denotes that at the time of the deposition of the sandstone layers there were bodies of trap undergoing erosion in the neighboring region: they may have been derived from the front of this very sheet before it had advanced so far as the locality in question.

The upper surface of the trap forming Saltonstall Mountain is extremely vesicular and irregular; the vesicles are sometimes well defined, sometimes vague, indicating both gas expansion and replacement as their cause. The texture shows a distinct decrease in coarseness as we approach the upper contact, although the upper portion, as a general rule, is more coarsely crystalline than the lower portion in contact with the sandstone. Pumpelly speaks of this fining of the texture on ap-

<sup>1</sup> Geol. Conn., 1842, p. 383.



proaching the upper surface as common to all amygdaloids studied by him in connection with the copper-bearing rocks of Lake Superior; and these sheets are well known to be extrusive.<sup>1</sup> It is to be noted here that coarseness of texture, even at the base of lava flows, presumably depends, other factors being the same, on whether extrusion takes place on land surfaces or under water; so that we should expect the trap to be much finer in grain when extrusion takes place under water, since texture is a function of rate of cooling.

When a section across the upper contact is examined under the microscope, the lamination of the sandstone, which occupies the inequalities in the upper surface of the trap, is seen to conform to the general contour of the hollows. This conformity is usually visible in the thin section, even when not noticeable in the hand specimen; it is of common occurrence in other localities along the eastern ranges, and is highly significant of the deposit of the sandstone subsequent to the eruption of the trap. Sections of the trap at the upper surface of the sheet also exhibit vesicles, more or less open upwards, which are partly or wholly filled with stratified elastic deposits, connected with the overlying sediments by narrow necks. In some cases the sand-filled cavities are apparently isolated in the trap, but this appearance is owing to the fact that the thin section is transverse to the opening along which the sand grains filtered into the cavities. The elastic grains occupying the vesicles are usually of the most enduring minerals derived from the ancient crystalline rocks, on the side of the Triassic estuary: these are quartz, various feldspars including microcline, hornblende, and muscovite, cemented together by granular calcite stained red by ferric oxide. Small fragments of vesicular trap occur here also, not the least interesting of the constituents. The grains first deposited are generally arranged with their longer axes roughly parallel to the contour of the lower portion of the vesicle; grains later deposited appear approximately parallel not only to one another, but to the general stratification of the main mass of overlying sandstone, and also to the stratification in a number of similar vesicles in the upper portion of the trap sheet at this point. So highly specialized an occurrence of elastic material in vesicles at the surface of a trap sheet can have but one interpretation: the trap sheet is extrusive. Like the conformity of the sandstone or shale to the upper surface of the trap, the elastic filling of the surface vesicles is very characteristic of the eastern ranges, and is

<sup>1</sup> Metasomatic Development of the Copper-Bearing Rocks of Lake Superior, *Proc Amer. Acad.*, XIII., 1877-78, pp. 282, 283.

particularly interesting in the way it recalls the details of the slow process by which these trap sheets were buried. Irving mentions the occurrence of filled vesicles at the upper surface of the diabases and diabase-porphyrites of the Keweenaw series of Lake Superior, and cites it as one of the strongest proofs of the extensive origin of these rocks.<sup>1</sup>

Fragments of vesicular trap are not uncommon in the sandstone immediately overlying the surface of the sheet; their edges appear somewhat water-worn. It is of course possible that such fragments as these might have been derived with the sand from some distant source, and that they therefore do not in any way bear on the contemporaneous extrusion of the subjacent sheet. In such a case we should expect to find fragments of trap at various horizons in the Triassic series, showing no definite association with the intercalated trap sheets, but this is not the fact. The sandstones and shales throughout the valley here and there contain abundant fragments of trap, but, except in a few cases that will be specified, the fragments occur only in the bed immediately overlying some one of the sheets of the eastern trap ranges; the fragments are commonly vesicular, and as such cannot have survived long transportation; they are moreover but imperfectly water-worn, if at all, and are sometimes angular, and can therefore be referred only to a source close at hand. It seems reasonable to conclude, on these several grounds, that the trap fragments in the sandstones that rest on the trap sheet of Saltonstall Mountain may be accepted as giving indication that the sheet had been formed before the deposition of the sandstone above it. The action of waves and tidal currents on the scoriaceous, irregular, and fragmental surface of a lava flow would be entirely competent to detach and transport relatively coarse pieces of the lava from more to less exposed situations, and mingle them with fine sands derived from more distant sources; and this process might continue with decreasing activity until the last remaining knobs of lava were buried under the growing sandstone cover. This interpretation is the only one that appears consistent with the facts here noted. The sandstone lying on the back of this trap sheet is distinctly harder than is common in the region, and our first impression was that its hardness was due to baking, and that the trap sheet was intrusive; but this is not in the least borne out by more careful study. The hardness of the sandstone is due to cementation by infiltrating calcite in chief part, and not at all to change from the ordinary structure of sandstone. The sandstone on

<sup>1</sup> The Copper-Bearing Rocks of Lake Superior, Monogr. V., U. S. G. S., 1883, pp. 79, 132, 140.

the back of the Totoket sheet, locality 16, is similarly indurated, and shows as little indication of baking.

In review, it may be said that the absence of any tendency towards a finer crystalline texture in the trap immediately at the contact with the larger sandstone areas, the highly vesicular texture of the upper portion of the mass, the parallelism of the axes of the sand grains and of the lamination of the deposits that they form, the connection of the sand filled vesicles by narrow necks with the sandstone above, and the occurrence of trap fragments in the overlying sandstone beds, all point to the extrusive origin of the trap sheet, and to the subsequent deposition of the sandstone upon it. After reaching the conclusion that the Saltonstall sheet is extrusive, it may be profitably compared with the West Rock and Gaylord Mountain sheet. The first contrast to be mentioned, and the one most conspicuous in the field, is the presence of numerous vesicles in the upper portion of the eastern sheet, and their absence in the western: this we would refer to the small pressure upon the surface of the extrusion at the time of its cooling. The few vesicles near the base of the sheet may have been produced at the front of the advancing flow, when its thickness was not so great as afterwards. Next may be mentioned the general holocrystalline, non-porphyrific, and relatively coarse texture and the small degree of alteration of the western sheet, while the eastern is more or less glassy and porphyritic throughout, and greatly altered. The eruption into water and the highly scoriaceous texture of the upper portion must have favored quick cooling and subsequent alteration in the eastern sheet, without normal subaerial weathering; the effect of the presence of much glassy base must also be considered, for this is peculiarly prone to alteration; it is now as a rule wholly devitrified to chloritic substances, microliths, ferrite, etc. But none of these factors could affect the intrusive sheets; their imprisonment between the beds deep below the surface would allow them to cool slowly, and thus acquire a coarse texture, and would decrease the rate of hydration and alteration; for these reasons we find them preserving in a great degree their original characteristics. It should be noted, however, that inasmuch as a thin extrusive sheet is vesicular through a greater proportion of its mass than a thick sheet, thick lava flows may be much less altered than thin ones. Thus the heavy sheet of Mount Tom in Massachusetts is practically anhydrous, while the thinner sheet of Saltonstall Mountain contains 3.9% of water.<sup>1</sup> Finally, there is a most marked and per-

<sup>1</sup> Hawes, *loc. cit.*

sistent contrast between the features of the upper contact in the western and eastern sheets. These need not be again stated; suffice it to say that the features of the western sheet demonstrate the trap to be secondary to the sandstone, while those of the eastern sheet are equally conclusive in showing the sandstone to be secondary to the trap. It does not seem too much to say that all the many peculiar features of these two sheets find reasonable explanation as consequences of the strongly different conditions of their origin.

The localities referred to above as yielding trap fragments, but not lying on the back of a trap sheet, are the trap conglomerate of the anterior to Lamentation Mountain, which is certainly the stratigraphic equivalent of the adjacent trap sheet; the heavy trap conglomerates northeast of the first posterior ridge to Saltonstall Mountain, which are perhaps to be associated with the posterior, although probably dislocated from it by faults; and a single case south of Durham, where one fragment of vesicular trap was found in a conglomerate, distant from any trap sheet, but near the eastern crystalline boundary of the formation.

*Meriden Quarry. Locality 19 (Figs. 5, 18).*—The Meriden City quarry, in the easternmost ridge of the Hanging Hills group, has been attentively studied, and with much profit. Suites of specimens were carefully collected from above and below the surface of separation between the upper and lower masses of trap which appear here, with a view to examining the evidence of double flow presented. Numerous specimens were also taken from the linear breccias of sandstone and trap fragments which traverse the quarry, in order to compare them with fragments of sandstone included in trap, such as occur in a dike at Mount Carmel, locality 27, several miles to the southwest, and to discover if they should in any way bear on the intrusive or extrusive origin of the Meriden sheet.

The lower mass of trap, *a, a*, Fig. 18, is seen beneath the upper, *b, b, b*, on the west side of the quarry, where abundant evidence may be found to show that the two were produced by separate eruptions. They are divided by a somewhat irregular surface, like that of rolling ropy lava, and usually marked by a seam, more or less open to the weather. The lower trap is changed to a reddish brown color for a depth of three feet or more below its upper surface, and contains numerous amygdular areas of chlorite, giving it a mottled appearance, simulating an altered sandstone to the eye. The reddish brown color gradually disappears down-

ward, and at four feet below the junction it is replaced by an earthy blue-green trap having abundant amygdules of chlorite and calcite, and to the eye appearing much fresher than the reddish trap.

Numerous sections were cut from the red superficial portion of the lower sheet, and from its contact with the dense trap of the upper sheet, in order to detect any clastic material that might occur there. Very little was found, but immediately upon the upper surface of the lower sheet a thin layer was discovered consisting of rudely stratified grains of clastic quartz and orthoclase, mixed with angular fragments of trap, like that of the red seam. Some of the trap grains are glassy, non-polarizing, and of a light green color, thickly sprinkled with minute dots of ferrite. They are probably fragments of the pumice-like surface of the lower sheet; other grains are amygdaloidal, and contain small ledges of some triclinic feldspar. The whole is cemented together by quartz and calcite. There is no marked tendency towards a stratified arrangement of the grains, such as characterizes deposition in water. The trap grains appear to have been the result of the comminution of scoriæ on the surface of the lower sheet during the ordinary progress of subaerial erosion, while the occasional grains of orthoclase or quartz may have been deposited by wind or stream action; and from this we have supposed that the thickness of the lower sheet was somewhat greater than the depth of the water into which it flowed. Hitchcock long ago noted that the reptilian tracks in the sandstones in Massachusetts occurred chiefly in the beds closely overlying the trap sheets, as if the depth of the Triassic estuary had been decreased for a time by the lava that had flowed into it.

The lower trap of the quarry at ten feet below the red seam, where it is the least altered as far as the quarry exposes it, is fine-grained, of a dark greenish blue color, and of a uniform texture, containing abundant amygdaloidal cavities. Mineralogically it is composed of extremely altered porphyritic crystals of plagioclase in a ground mass of minute crystals of the same, which are in turn set in a matrix of the unindividualized base. The base in places is a yellowish green glass, and in others is wholly devitrified. The augite that it undoubtedly contained originally has been entirely removed by alteration. Calcite and secondary quartz are abundant, the former so plentiful that the rock effervesces readily, even with very dilute hydrochloric acid. Under the microscope, the rock appears profoundly decomposed; its numerous amygdules being due to replacement, with the occasional exception of a well-outlined cavity, the result of gas expansion. Admitting the original

presence of augite, the lower sheet would be classed as a glassy form of augite-porphyrite.

The texture of the rock steadily grows finer, and the cavities due to gas expansion more numerous, as we approach the surface of junction with the upper sheet; and there is at the same time a marked increase in the amount of glass forming the base. At five feet below the contact the vesicles occupy nearly one fourth of the space, and in slide 140 of our collection they are seen to be elongated parallel to the surface of contact, as if indicating flowing action. The origin of the vesicles by gas expansion is beautifully shown in this slide by the well marked tangential arrangement of the feldspar crystals about the elongated and tortuous amygdaloidal cavities, conforming even to their minor irregularities. Sections from the red seam, just under the junction, show this portion of the trap to have been blown almost to shreds by the escaping gases. The scoriaceous character here cannot be doubted; fully two thirds of the rock is made up of secondarily deposited calcite and quartz, filling the irregular cavities and vesicles of the porous mass. The inter-vesicular areas consist of a greenish glass, thickly sprinkled with hair-like microliths of feldspar and an occasional porphyritic crystal of the same. The red color of the seam is due to the formation of iron sesquioxide. Hawes noted that the oxidation of iron-bearing minerals exposed to surface weathering is from the protoxide to the sesquioxide state, while the change is from one protoxide to another when not thus exposed, as is true of the eastern ranges.<sup>1</sup> It therefore seems likely that in this instance the red color of the surface of the lower sheet indicates surface weathering before the upper sheet was erupted, thus confirming the suggestion already made, that the thickness of the flow was great enough to raise its surface above water. It is rare that this red color is seen in the traps of the Triassic area.

The scoriaceous character of the sheet at its upper surface is much more strongly marked than in others thus far examined in the Connecticut valley; this is also thought to be connected with the appearance of the surface of the sheet above the surface of the body of water into which it flowed. Cooling under the air must have taken place much less rapidly, and under much less pressure, than when below the water surface, thus permitting a more complete expansion of the occluded gases and the production of a highly pumiceous surface layer.

The trap of the upper sheet just above the red seam appears in the hand specimen much less altered than that from below. Even at the

<sup>1</sup> Amer. Journ. Science, IX., 1875, p. 190.



contact with the scoriaceous upper surface of the lower trap, the rock is sufficiently coarse to detect porphyritic plagioclase crystals; but amygdules are entirely wanting. Under the microscope a few pseud-amygdaloidal areas are seen. The rock shows evidence of an original glassy base, seen in the triangular areas between ledges of feldspar; it is made up of triclinic feldspar, magnetite, and occasionally a minute grain of olivine. There is a slight local tendency toward a porphyritic structure; but this is lost ten feet above the lower trap. Calcite and chlorite, the usual decomposition products, occur at the base, the latter being sufficiently abundant to give the rock a greenish color next above the red seam; this is lost ten feet above the contact, and the great mass of the upper sheet is of a very dark bluish color and holocrystalline. The mineralogical composition given above is that of a normal diabase, the amount of olivine being so small that it can hardly be classed as an olivine-diabase. While the upper surface of the lower trap is abnormally scoriaceous, the base of the upper sheet is abnormally coarse and free from vesicles, as compared with other trap sheets resting on sandstones or shales. This can be explained by the well known poor conductivity of volcanic scoriaceous substances, whose presence here permitted the upper trap to cool and solidify slowly, and produce a more complete crystallization. A practical illustration of the low conductivity of such material is found in the use of ~~scum~~ or slag from iron furnaces as a packing for steam pipes.

The lower sheet may be confidently called an extrusion, but as far as this quarry goes, there is nothing to determine the origin of the upper sheet. This, however, is fully settled by the general field evidence of the region, which correlates this whole mass with the heavy sheet of Lamentation Mountain, and that sheet has been clearly shown to be extrusive.

The field evidence here referred to concerns the occurrence of faults, which, as is so generally the case, are at nearly all points buried under surface waste. It is therefore of particular interest to examine the bands of breccia (*c, c, c*, Fig. 18) by which the quarry is characterized, as they are best interpreted as small examples of the great dislocations by which the structure and topography of the formation are deciphered. The breccias therefore deserve attentive study. The apparently unbedded sandstone, of which they in good part consist, is best interpreted as a fine clastic filling of the fault fractures, derived from above, where the walls were of sandstone or shale, and gradually filtered down among the large and small angular blocks of trap that were broken from the quarry



sheets ; but, on the other hand, the sandstone might also, until its continuity in bands across the quarry was noticed, be regarded as fragments of sandstone picked up and included in the trap at the time of its eruption : not that such inclusions would necessarily indicate intrusion, for extrusive sheets are well known to contain fragments of the adjacent country rock.

The general attitude of the several bands of breccia negatives the second interpretation. The bands all maintain a straight course through the quarry ; a single band may cut the lower, as well as the upper sheet ; the bands stand at right angles to the general extension of the sheets ; they are parallel to one another and to the course of the large faults by which the region is broken. The dividing surface between the lower and upper sheet in the southern end of the quarry is seen to be dislocated by one of the bands, with small heave on the east, this being the relative displacement of the large faults in the region. Neglecting this sufficient series of indications of their origin, we examine their structure more closely, and discover that they are frequently slickensided, and that the trap fragments that they contain are sometimes broken since taking their places in the bands. Moreover, these trap fragments are themselves included in the sandstone matrix of the bands ; the fragments are angular, and show no variation of texture from centre to surface ; the sandy matrix contains small broken grains of sandstone, as well as of sand. Again, if the sandstone which accompanies the trap fragments had been picked up and included in the main mass of trap at the time of eruption, it should present evidence of the action of heat, as in induration, or more likely in some alteration, for the relatively small areas of sandstone in so large a mass of trap must have long been subjected to intense heat. With this idea in mind, a comparison was made of sandstone from the breccia bands with a block of sandstone in a large dike a little north of Mount Carmel station, New Haven and Northampton Railroad, locality 27, to which Professor Dana had called our attention. The blocks of sandstone in this dike are five or six feet long and two or more wide. When struck with a hammer they give a ringing sound, characteristic of induration. Sections of the sandstone show it to be principally composed of quartz grains mixed with fragments of feldspar, and closely cemented by a clayey material. While it exhibits no significant alteration in composition from ordinary sandstone, it cannot be doubted that its exceptional density was the result of the dehydrating action of heat from the molten dike on the kaolinite that formed the clayey cement. The contact of

the dike and sandstone is sometimes blurred, as if they had been locally melted together; and the texture of the dike becomes finer on approaching close to the included sandstone fragments, just as it does on approaching its sandstone walls.

Returning to the quarry, we find that the sandstone from the breccia bands has no indication of induration, except that resulting from the moderate cementation of its elastic material by secondary quartz and calcite deposited around the grains. Sections of the sandstone in contact with the included trap fragments and with the main mass of the trap sheet show a well marked laminated arrangement of the sand grains nearly parallel to the walls of trap and to the faces of the trap fragments; this points decisively to the deposition of the sandstone posterior to the eruption and fissuring of the trap. There is also a laminated arrangement of the sand grains on all sides of the trap fragments, as far as examined, which we do not fully understand, but which may be perhaps interpreted as indicating continued motion of the faulted masses while the breccia was still moist and soft, every trap fragment moving as a whole and thus calling for an adjustment of the sand grains around it. There is no change in the texture of the enclosing mass of trap on approaching the breccia bands, such as would certainly appear if the sandstones were inclusions. A change of texture is so characteristic of rapid marginal cooling that it is often shown immediately at the border of large amygdaloidal cavities, as has been mentioned by Pumpelly,<sup>1</sup> and as is well marked in our slide 141, from near the upper surface of the lower trap in the Meriden quarry, and again still better in slide 218 from the Middlefield Railroad cut, locality 22, in which a nearly spheroidal vesicle is surrounded by a layer of trichitic glass having an area as large as the vesicle itself.

In order to apply this test carefully to the case in hand, several sections were cut from the trap in the quarry, on either side of the best exposed breccia, at the contact, and one and four feet away. These show no tendency towards a finer grain, or towards a development of porphyritic crystals or glassy character on nearing the breccia; the character of the trap remains constant to the contact. Moreover, the angular fragments of trap in the breccia are of uniform texture, and are identical with the trap on either side, except for a little greater weathering in the former. These fragments may therefore have been derived by fracture directly from the enclosing walls; but certain minute grains of very fine-grained decomposed trap, also occurring in the breccia, appear to

<sup>1</sup> Metasomatic Development of the Copper-Bearing Rocks, *loc. cit.*, p. 283.

have been derived from the upper surface of the surrounding trap, or from another trap mass above.

We therefore conclude, in reviewing the examination of the breccias, that sand and sandstone grains and a moderate share of rounded grains of close-textured normally eroded trap were all filtered together down the fissures that traversed the sandstones and trap sheets, and that on reaching the points exposed in the quarry they found a confused mass of large and small angular fragments of trap, broken from the walls at the time the fissures were made, the whole forming a highly characteristic breccia. Such breccias are not uncommon in the valley, as at Branford, locality 21 (Fig. 17), where they are associated with the great fracture by which the formation is bounded on the east; and in the Tariffville Railroad cut, locality 13, of minor importance. Percival knew a few of them, and called them "clay dikes."<sup>1</sup> While our conclusion may therefore be considered well supported, it must be remembered that the breccias do not afford any evidence as to the intrusive or extrusive origin of the trap sheets, and are therefore to be regarded as of secondary importance in this essay, however valuable they may be structurally.

*Tariffville. Locality 13.*—One fourth of a mile east of Tariffville station on the Connecticut Western Railroad (Fig. 8), a cut exposes a valuable section of the anterior ridge.<sup>2</sup> The greater part of the cut is in massive trap; a narrow band of breccia occurs near its middle. At the eastern end of the cut, the upper portion of the sheet shows a thin bed of tufaceous material, which locally passes into a bed of trappy sandstone along the strike; and above this there is a second sheet of compact trap of moderate thickness, with its upper surface lost in drift. The two sheets together constitute the anterior ridge at this place. There appears to be little if any lithological distinction between them; they are both glassy varieties of augite-porphyrite. The upper surface of the lower trap, although generally amygdaloidal, is not so much so as is usually the case. Immediately beneath the sandstone layer, the amygdaloidal cavities have an aberrant character, being several inches in length and generally about one fourth of an inch in diameter, with their longer dimension normal to the surface of the sheet. Amygdules in such cavities have been described from one of the extrusive copper-

<sup>1</sup> The relation of these breccias to the faults of the region is more fully discussed in a previous Bulletin of this volume, No. 4, p. 77.

<sup>2</sup> See an account of this locality by W. North Rice, in the Amer. Journ. Science, XXXII., 1886, pp. 430-433, where it was first brought to public notice.

bearing traps in the Lake Superior region, where many of them were composed of native copper; hence the name "spike amygdules," as given by Pumpelly.<sup>1</sup> Irving also mentions them from the same locality, and Hawes refers to similar ones occurring in the trap of Connecticut as "pipe-stem" amygdules.<sup>2</sup> Nason notes their occurrence in the trap of the Watchung Mountains in New Jersey,<sup>3</sup> which Darton thinks is of extrusive origin,<sup>4</sup> and Winchell reports them in greenstone from Thessalon Point, Ontario.<sup>5</sup> Their occurrence in the lower trap of the Tariffville cut is restricted to a zone of little depth near the surface of the sheet, where it may be supposed that escaping gases found the easiest direction of expansion to be toward the surface; hence their peculiar position. A fortunate breaking of the trap may liberate one of these rod-like amygdules; they are composed of concentrically deposited calcite with a chlorite centre, or more rarely the chlorite centre is wanting and the amygdule is now hollow. An occasional amygdule of ordinary form associated with the spike amygdules is beautifully banded, with its lamination parallel to the stratification of the sandstone above, and hence dipping with it at the same angle, about twenty-five degrees southeastward. Under the microscope, the bands are seen to be composed of granular calcite and secondary quartz, the banding being due to fluctuations in the supply of ferric iron during the process of filling the vesicles. The lower part of the amygdules is extremely granular and ferruginous; the upper part usually consists of composite calcite individuals, and is free from iron. Some amygdules near the surface contain grains of elastic quartz or orthoclase lying in the calcite filling, as is so common in the eastern sheets, and arranged with the major axes of the particles parallel to the bedding of the sandstone and lamination of the amygdule. Cavernous amygdules with banded structure were also found in the Farmington anterior ridge, locality 12. Their only other occurrence in this country as far as known, is in the amygdaloidal melaphyse at Brighton, near Boston, Mass., where the great number and essential parallelism of the bands to one another, and to the bedding of the overlying slates, has been taken to indicate deposition of some kind guided by gravity.<sup>6</sup> In all these cases it may be fairly argued that

<sup>1</sup> Proc. Amer. Acad., XIII., 1877-78, p. 296.

<sup>2</sup> Amer. Journ. Science, IX., 1875, p. 191.

<sup>3</sup> Geol. Survey of N. J., Report for 1888, p. 37.

<sup>4</sup> Amer. Journ. Science, XXXVIII., 1889, p. 134.

<sup>5</sup> Geol. and N. H. Survey of Minn., XVII., p. 15, Plate I.

<sup>6</sup> Proc. Boston Soc. Nat. Hist., XX., 1878-80, p. 426

the accordance of the bands in the various amygdules with the bedding of the adjacent sedimentary layers demonstrates the eruption of the igneous sheet before the deformation of the whole mass ; but manifestly it does not bear on the manner of its eruption.

The microscope reveals a marked decrease in the coarseness of the texture of the trap upwards as the overlying sandstone layer is approached at the eastern end of the railroad cut, and a corresponding decrease in the freshness of the rock ; but the texture nowhere becomes so fine as that on the back of Gaylord's Mountain. The intermediate sandstone at the south end of the cut contains fragments of amygdaloidal trap in abundance, often water-worn ; but a little distance to one side, this mixture is replaced by a strongly marked tufa bed in the same horizon, resembling in color and appearance the lapilli from the ash and bomb deposit in the Lamentation anterior, locality 8 ; under the microscope it shows decomposed fragments of glassy trap in a cement of calcite and chlorite with occasional fragmental grains of quartz and muscovite.

The upper trap sheet does not present significant features in the railroad cut, but descending to the river and crossing by the road bridge, where its upper surface is apparently found, several exposures occur a little way up stream, in which there is the usual mixture of trap fragments with the sands of the sandstone that overlies the sheet. This is thought to be the upper surface of the upper anterior sheet, because no other trap outcrop is to be seen until the base of the heavy main sheet is reached.

The breccia in the middle of the cut resembles the breccias of the Meriden quarry, but is much narrower, being only four to six inches wide. It is a fissure in the trap, on which some slight faulting has taken place, as is shown by slickensides ; it is filled with a mixture of sand and angular trap fragments, and was undoubtedly formed posterior to the production of the trap.

## 5. — Conclusions.

It is difficult for those who have become convinced of the correctness of a certain conclusion to state in an impartial manner the evidence on which the conclusion rests. We shall therefore not attempt to review all the evidence presented above, but will briefly call attention to the uniform association in the eastern trap ranges of the numerous characteristics of extrusive sheets, while the western trap range as consistently

manifests the several characteristics of an intrusive sheet. It must be remembered, too, that of the numerous localities instanced on the eastern ranges, all (with one exception, Hartford) belong to only three extrusive sheets; and hence the evidence that is found at one point supplements or confirms that found at another in a most satisfactory manner. All this seems to us to be beyond explanation either by accidental coincidence or mistaken identification. While judgment might well be suspended if our argument rested on single examples, or on numerous examples confusedly arranged, it is difficult, even if necessary, to maintain an open mind in the face of evidence at once so full, so varied, and so accordant. If all the trap sheets of the region were of one kind, the argument would be weakened; for in the absence of either kind of sheet, the peculiarities of the other would not be illumined by the light of contrast. The presence in the single region under consideration of sheets with the features of intrusions and extrusions therefore greatly increases the confidence that one may feel in the case, and warrants the acceptance of those sheets that we have called extrusive as conformable and contemporaneous members of the Triassic series, by means of which the dislocations of the formation can be detected.

The fullest statement of the method by which the extrusive trap sheets can be thus employed is given in the article above referred to,<sup>1</sup> by the senior author, in which the process of investigation followed by the advanced section of the Harvard Summer School of Geology during a week's work about Meriden is presented in detail. It is now our design to continue the investigation in the district northwest of Hartford, where a preliminary excursion has indicated a change in the course of the faults from the uniform northeast trend that they possess in the Meriden district. When the faults are mapped out over a considerable area, comparison can be made between their course and the strike of the schists on either side of the Triassic valley, on which the course of the dislocations is thought to depend.

<sup>1</sup> The Faults in the Triassic Formation near Meriden, Conn., Bull. Museum Comp Zool., Geol. Series, I., 1889, pp. 61-87.



## EXPLANATION OF PLATES.

## PLATE I.

- Fig. 1. Map of Triassic area in Connecticut from Long Island Sound to the north bend of the Farmington River, based on Percival's map in his *Geology of Connecticut*. The numbers in circles refer to localities on the several trap ridges described in the text, and in most cases figured on a larger scale in later plates. See page 104.

Plates II. and III. contain outline maps traced from town maps in county atlases, the trap ridges being sketched in black; they cannot claim much accuracy, but will probably serve as guides to the localities that furnish exposures of critical contacts.

## PLATE II.

- Fig. 2. Adjacent ends of Saltonstall and Totoket Mountains. For locality 14, see p. 110; locality 15, see p. 111.  
Fig. 3. North end of Totoket Mountain. Locality 4, see p. 107; locality 16, see p. 111.  
Fig. 4. North end of Higby Mountain. Locality 6, see p. 107; locality 17 and 17', see p. 111; locality 24, see p. 115.  
Fig. 5. Chauncy Peak, south end of Lamentation Mountain, and Quarry Ridge, Meriden. Locality 7 and 7', see p. 108; locality 8 and 8', see p. 108; locality 19 and 19', see pp. 112, 113.  
Fig. 6. Notch Mountain and eastern ridges of the Hanging Hills. Locality 9 and 9', see p. 109; locality 10, see p. 109; locality 19 and 19', see pp. 112, 113.

## PLATE III.

- Fig. 7. Farmington Mountain and its anterior ridge. Locality 12, see p. 109.  
Fig. 8. Farmington River Gap, at Tariffville. Locality 13 and 13', see p. 110.  
Fig. 9. Rock Falls of Aramamit River. Locality 23, see p. 114.  
Fig. 10. North end of Lamentation Mountain. Locality 18, see p. 112.  
Fig. 11. Posterior ridges to Saltonstall Mountain. Locality 20, see p. 113; locality 21 and 21', see pp. 113, 114.

## PLATE IV.

- Fig. 12. Overlying sandstone traversed by a small leader from the trap sheet of Gaylord's Mountain at Roaring Brook, locality 3. See pp. 115 and 116.
- Fig. 13. Angular fragments of trap imbedded in sandstone on the back of the anterior ridge of Higby Mountain, half a mile southeast of East Meriden, locality 5. See p. 107.
- Fig. 14. Drawing from a microphotograph of a section of vesicular trap from the ridge posterior to Chauncy Peak at Highland Lake, locality 24. The trap is black, with white areas representing minute pseud-amygdules and an occasional prism of plagioclase; the large central space within the trap is an amygdale, containing clastic material (dotted) at the bottom, with the once horizontal lines of deposition now tilted parallel to the general monocline of the region; the upper part of the amygdale is filled with calcite, of which part is stained with some ferruginous material (fine lines), and the rest is composite crystalline calcite (blank). See p. 115.
- Fig. 15. Drawing from photograph of sandstone in contact with vesicular upper surface of trap, forming Lamentation Mountain, locality 18. The black areas are the thin walls separating vesicles; white spaces are amygdules of calcite. See p. 112.
- Fig. 16. Drawing from photograph of hand specimen of sand grains filling open vesicles in trap, Falls of the Aramamit River. Two vesicles have lower bands of calcite, and the remaining space filled with clastic material. Locality 23, see p. 114.
- Fig. 17. Breccia from fault in a road-cut in the second posterior ridge to Saltonstall Mountain, near Branford, locality 21. This fault is probably a branch of the great fault by which the Triassic formation is limited on the east. See p. 114.

## PLATE V.

- Fig. 18. The City Quarry at Meriden, looking northwest; locality 19. *a, a*, the lower flow in the southern part and the western alcove of the quarry; *b, b, b*, the upper flow, forming most of the mass here exposed; *c, c, c*, breccias of angular trap fragments and sandstone, traversing the quarry. See pp. 112, 127. The northern extension of Cat-hole Ridge is seen in the distance.